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RF Transceiver Reference Design Tuned for 915 MHz Using Wireless MCU AXM0F343

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REFERENCE DESIGN OVERVIEW

Introduction

This reference design contains a compact and efficient reference design for the AXM0F343 that demonstrates its operation in the 915 MHz ISM band. By using the design detailed below to implement the AXM0F343, it is intended that the time and risk associated with designing and certifying a final product can be greatly reduced.

The source design and fabrication files can be downloaded from the AXM0F343−x−915−x−GEVK web page located at https://www.onsemi.com/products/connectivity/wireless−rf−transceivers/axm0f343.

Design Schematic Overview

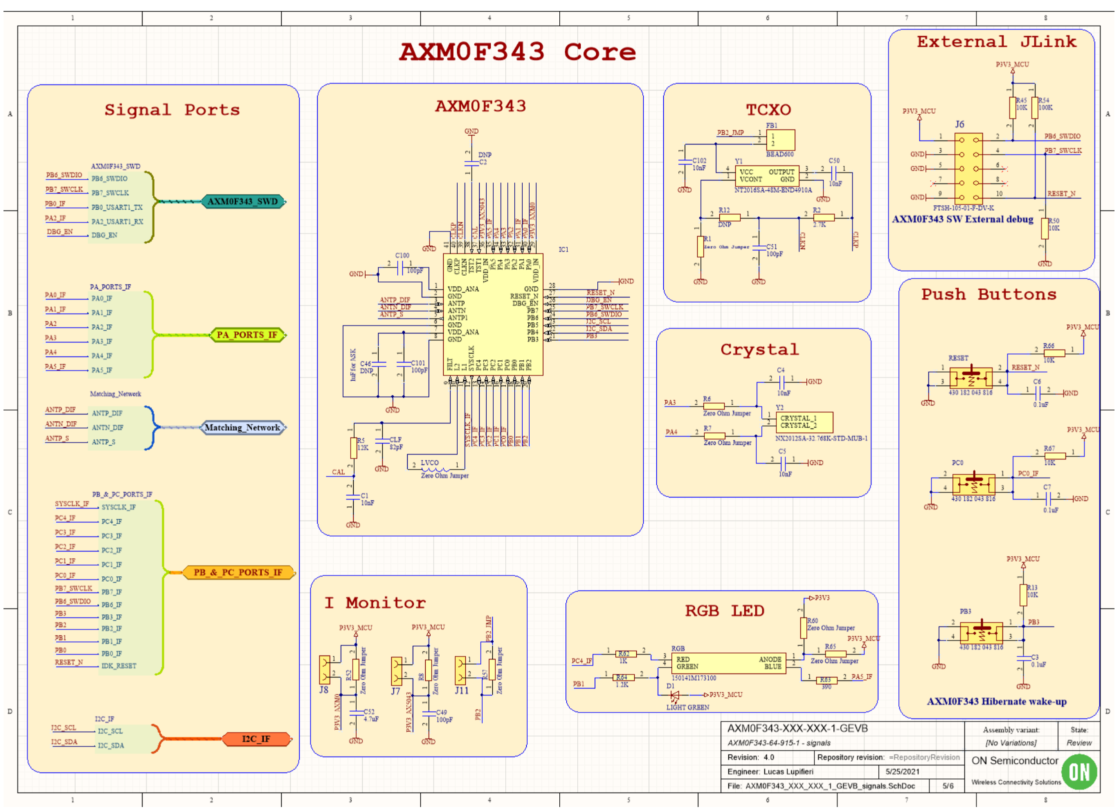


Figure 1. Design Schematic: Overview

Class–E Amplifier and Match Network

The AXM0F343 utilizes a class–E power amplifier, which includes components both internal and external to the IC. For this reason, the selection of component values between ANTP / ANTN and the antenna is not merely an impedance matching problem, but an amplifier design problem as well. This network must be tuned to the desired operating frequency for proper RF performance. Reference designs, including this one, have been provided by **onsemi** for commonly used frequencies. For additional details on tuning this network to different frequencies, see the References section at the end of this document. Note that typically this network is designed for optimal TX performance, and the frequency and gain tracking loops in the receiver will compensate to maintain the optimum RX sensitivity.

The network used in this design is shown in greater detail below. The components LC1/2, CC1/2, CT1/2, LT1/2, and CM1/2 are part of the class–E amplifier (PA choke and matching). CB1/2 and LB1/2 form a balun, and are used to transform the differential signal to single–ended. CE1/2/3, LE1, CF1/2/3, and LF1 are components of harmonic filters used to achieve an output spectrum that is compliant with regulations.

The values for 915 MHz are shown in the following image, as well as the bill–of–materials below. Note that the components labeled “DNP” are not necessary and can be removed for applications at this frequency.

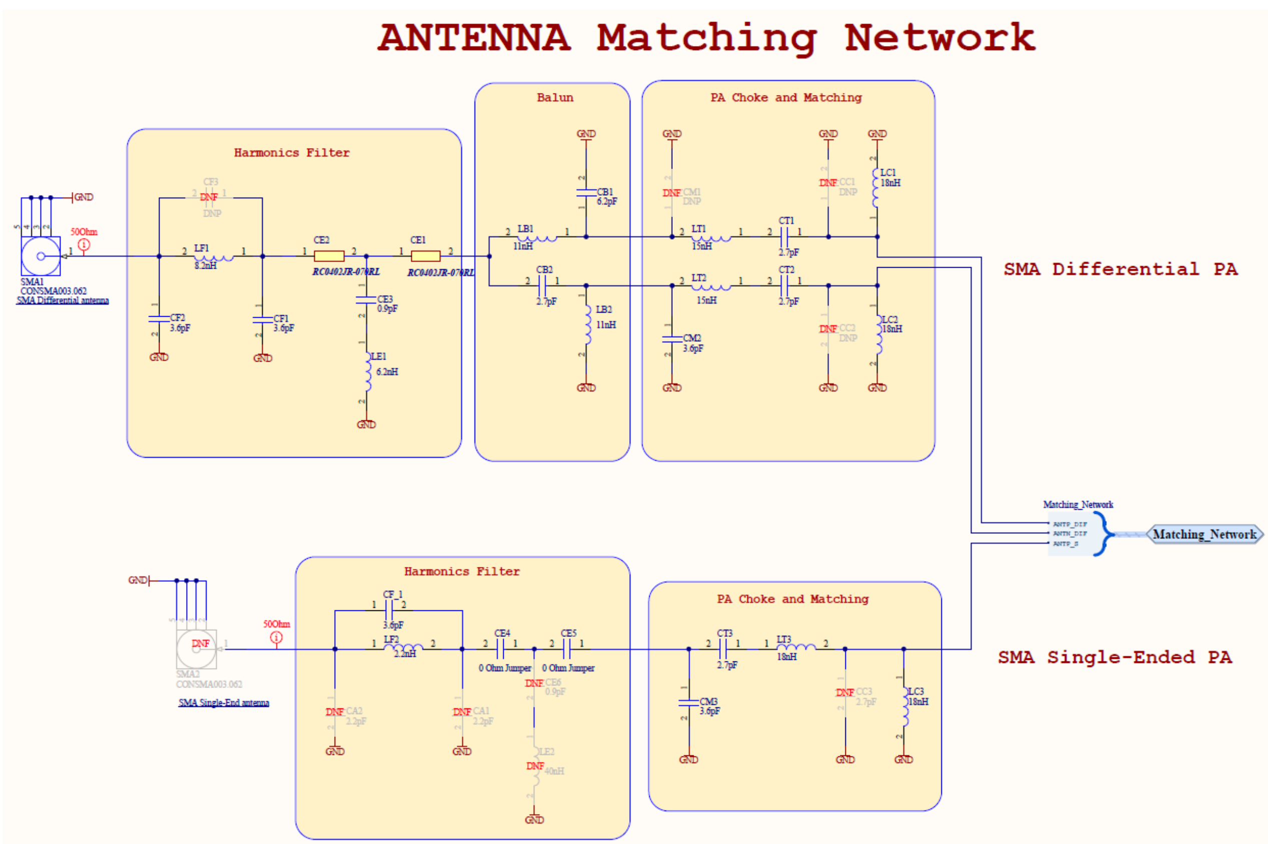


Figure 2. Design Schematic: Antenna Matching Network

TCXO and Optional XTAL

To achieve stable RF performance over temperature, a 48 MHz Temperature Controlled Crystal Oscillator (TCXO) is employed as a clock reference. This clock is connected internally to the radio transceiver core, but can also be made available to the

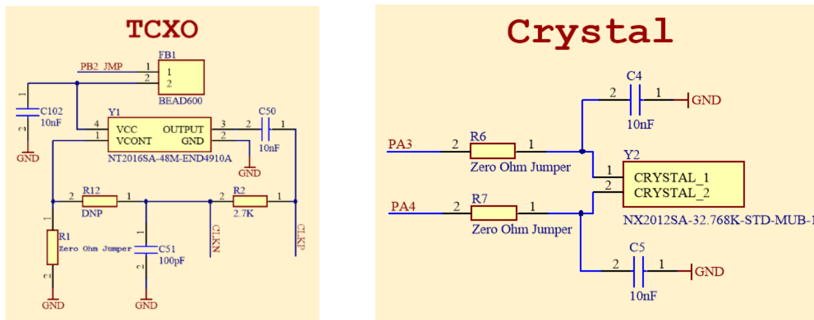


Figure 3. Design Schematic: TXCO and Optional Crystal (XTAL) Reference Clocks

VCO Calibration Hardware

To optimize the phase noise of the RF synthesizer, an optional VCO current calibration algorithm has been included in *easyAX5043.c* – a library that is used by AX−RadioLab. MCU core with software configuration via the SYSCLK pin. There is also an optional 32.768 kHz crystal that connects directly to the MCU core. The schematic for these components is shown in detail below.

To utilize this calibration routine, the following network between FILT and TST1 is required. TST2 must also be left floating. The implemented network is shown below, while more detailed information can be found in the dedicated app−note [https://www.onsemi.com/pub/Collateral/AND9858−D.PDF](https://www.onsemi.com/pub/Collateral/AND9858-D.PDF)

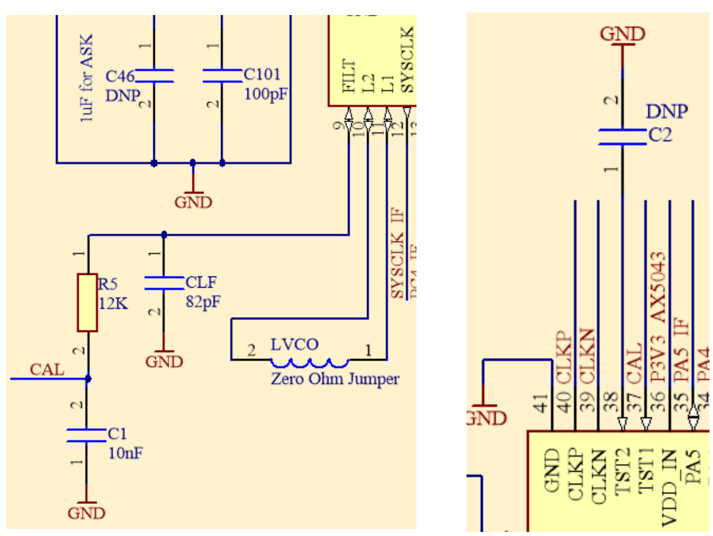


Figure 4. Design Schematic: VCO Calibration

PCB Layout & Construction

Top Layer:

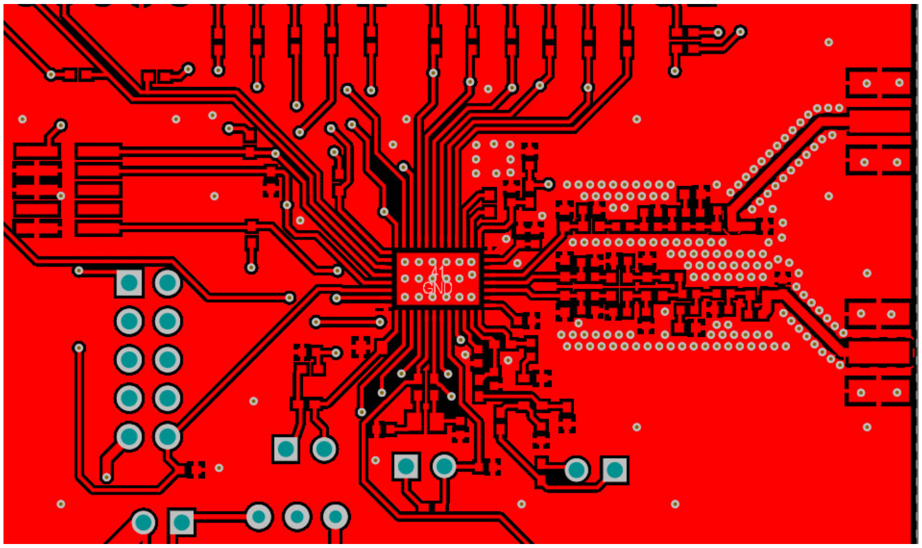


Figure 5. Top Layer

Bottom Layer (Mirrored to Reflect Physical View):

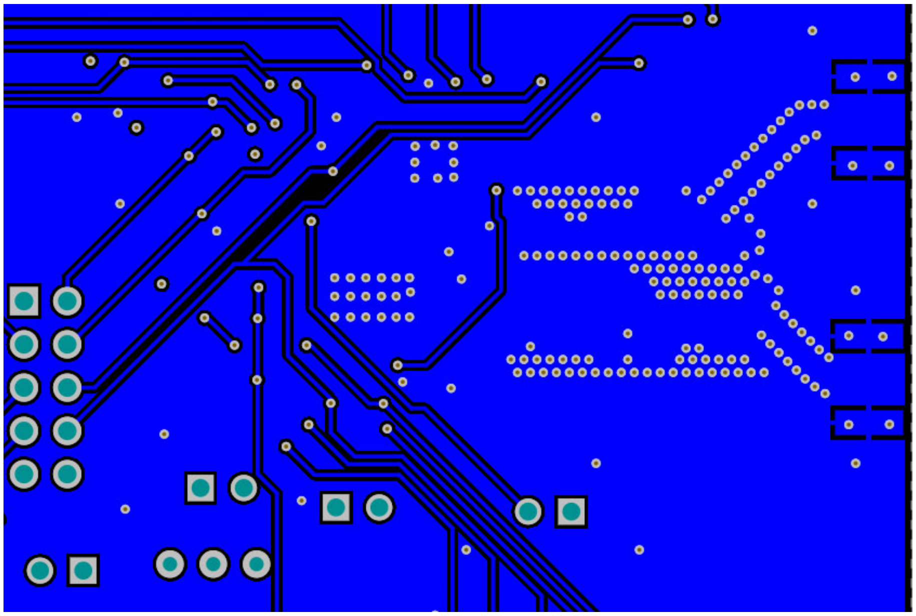
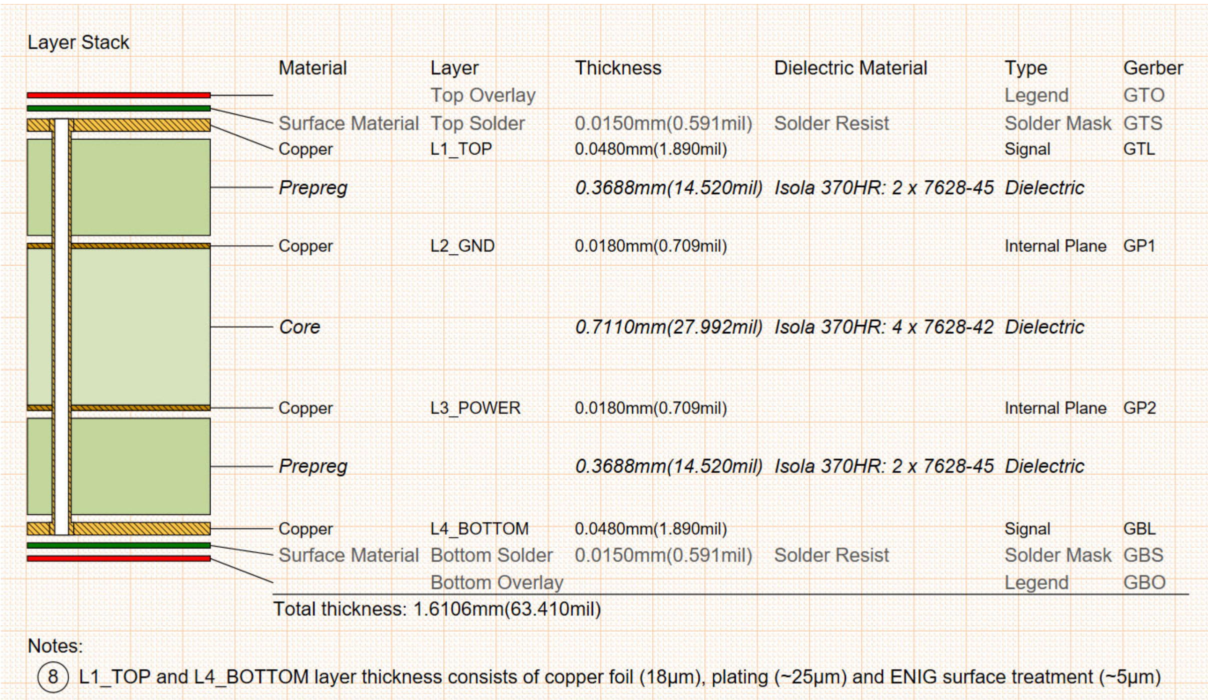


Figure 6. Bottom Layer (Mirrored to Reflect Physical View)

Layer Stack Up:

Table 1. LAYER STACK UP
(Four layer PCB, Isola 370 HR, 0.7 mm core, 35 μm (1 oz) copper.)

Stack Up	Layer Stack



Layer Stack

Material	Layer	Thickness	Dielectric Material	Type	Gerber
	Top Overlay			Legend	GTO
Surface Material	Top Solder	0.0150mm(0.591mil)	Solder Resist	Solder Mask	GTS
Copper	L1_TOP	0.0480mm(1.890mil)		Signal	GTL
Prepreg		*0.3688mm(14.520mil)*	*Isola 370HR: 2 x 7628-45*	*Dielectric*	
Copper	L2_GND	0.0180mm(0.709mil)		Internal Plane	GP1
Core		*0.7110mm(27.992mil)*	*Isola 370HR: 4 x 7628-42*	*Dielectric*	
Copper	L3_POWER	0.0180mm(0.709mil)		Internal Plane	GP2
Prepreg		*0.3688mm(14.520mil)*	*Isola 370HR: 2 x 7628-45*	*Dielectric*	
Copper	L4_BOTTOM	0.0480mm(1.890mil)		Signal	GBL
Surface Material	Bottom Solder	0.0150mm(0.591mil)	Solder Resist	Solder Mask	GBS
	Bottom Overlay			Legend	GBO

Total thickness: 1.6106mm(63.410mil)

Notes:
(8) L1_TOP and L4_BOTTOM layer thickness consists of copper foil (18μm), plating (~25μm) and ENIG surface treatment (~5μm)

Bill of Materials

The Bill of Materials (BOM) of the boards tuned for 915 MHz are the same apart from the AXM0F343 which can be marked as −64 or −256:

- https://www.onsemi.com/pub/collateral/axm0f343−64−915−1−gevk_bom_rohs.rev0.pdf
- https://www.onsemi.com/pub/collateral/axm0f343−256−915−1−gevk_bom_rohs.rev0.pdf

FCC TITLE 47 PART 15 PRE−COMPLIANCE TESTING

Overview of Regulations

US FCC title 47 part 15 regulates the use of radio frequency devices. The following sections are relevant to this context:

1. US FCC 47 § 15.247 – Contains the regulations covering the frequency bands including 902 – 928 MHz
2. US FCC 47 § 15.249 – Contains regulations for frequency bands including 902 – 928 MHz. This section allows for more flexibility in the modulation scheme and use case, but has a lower transmit power limit

3. US FCC 47 § 15.205 – Defines the restricted bands of operation
4. US FCC 47 § 15.209 – Defines the radiated field strength limits for emissions in the restricted bands of operation.

The purpose of this section is to detail the subset of tests that have been performed, along with their results, to demonstrate the compliance of a typical AXM0F343 902−928 MHz application with the FCC standard. For the context of this document, only the compliance with section 15.247 will be examined.

Section 15.247 Summary

Section 15.247 requires devices operating in the 902−928 MHz band to use either a frequency hopping or digital modulation scheme. Due to the wide bandwidth requirement for the specified digital modulation scheme, and the fact that the AXM0F343 is a narrow−band transceiver system−on−chip, the device will be tested using the frequency hopping requirements.

Compliance with the frequency hopping scheme is determined by the following specifications:

1. Frequency hopping systems shall have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater. [§ 15.247(a)(1)]
2. The system shall hop to channel frequencies that are selected at the system hopping rate from a pseudo randomly ordered list of hopping frequencies. Each frequency must be used equally on the average by each transmitter.
   [§ 15.247(a)(1)]
3. If the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system shall use at least 50 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 20 second period; if the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system shall use at least 25 hopping frequencies and the average time of occupancy on any frequency shall not be greater than 0.4 seconds within a 10 second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz. [§ 15.247(a)(1)(i)]
4. The maximum peak conducted output power of the intentional radiator shall not exceed the following: 1 watt for systems employing at least 50 hopping channels; and, 0.25 watts for systems employing less than 50 hopping channels, but at least 25 hopping channels. [§ 15.247(a)(2)(b)(2)]
5. In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement, provided the transmitter demonstrates compliance with the peak conducted power limits. [§ 15.247 (d)]
6. Radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) [§ 15.247 (d)]

Because the AXM0F343 is a software−configurable transceiver system−on−chip, and **onsemi** has provided firmware libraries that give the developer control over operating frequency, compliance with the frequency hopping components of the FCC regulations is determined by the final application. For this reason, tests specifically related to the use of frequency hopping channels are omitted from this document. The regulatory tests detailed in this document are the following:

1. 20 dB Bandwidth
2. Peak Conducted Power
3. Spurious Conducted Emissions

The purpose of this section is to detail the subset of tests that have been performed, along with their results, to demonstrate the compliance of a typical AXM0F343 915MHz application with the FCC regulatory standard. Note that the following is not a complete certification report. Several specifications required for certification were not applicable to the context of this design note and are not included.

Test Setup & Equipment

All tests were performed using conducted mode. Python scripts were used on the host PC to control the testing equipment, gather, and process the collected data. This section provides an overview of the test setup and equipment. Details pertaining to each test are given in the following section.

Equipment Used:

Table 2.

Lab Equipment	Type	Manufacturer
Signal Analyzer 13.6 GHz	FSV−13	Rhode & Schwartz
Signal Generator	SMU200A	Rhode & Schwartz
6 $^1/_2$ Digit Multimeter	34461A	Keysight
USB / GPIB Interface	GPIB−USB−HS	National Instruments

Equipment Setup:

The following block diagrams show the setup for the transmitter tests comprising a Signal Analyzer, and for sensitivity measurement using a Signal Generator.

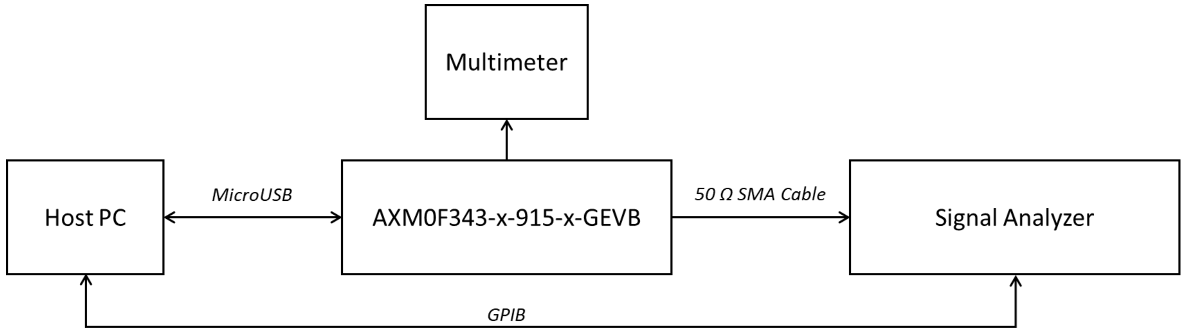


Figure 7. Setup for transmitter test

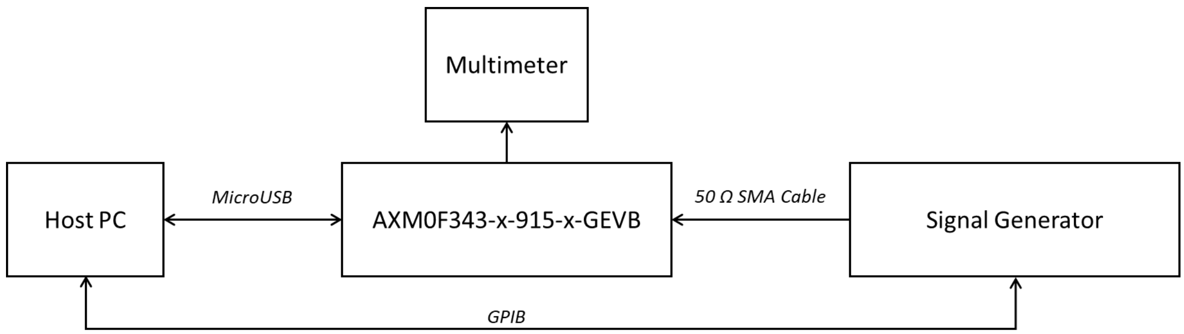


Figure 8. Setup for sensitivity measurements

Cable Loss

The loss in the cable connecting the transmitter to the signal analyzer was measured to be 0.95 dBm. The results shown below are the values recorded directly from the measurement equipment, and do not account for the cable loss.

Test Signal Description

For each transmitter test, the AXM0F343 was programmed with AX−RadioLab to transmit a random stream of bits with the following physical layer parameters:

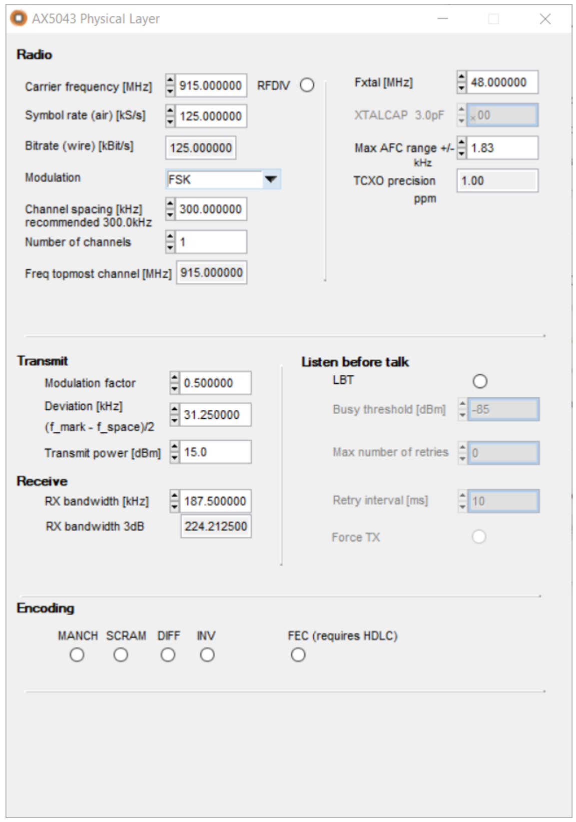


Figure 9.

Temperature & Supply Voltage

All tests were conducted at room temperature. For a full certification test, temperature and supply voltage extremes would need to be tested for most specifications.

Test Results

20 dB Bandwidth

This test measures the 20 dB bandwidth of a modulated signal, which is used to determine the required number of frequency hopping channels as per § 15.247(a)(1)(i).
The measurement parameters used are shown below:

Table 3.

Measurement Parameters	
Detector:	Positive Peak
Sweep Time:	Auto
Resolution Bandwidth:	5 kHz
Video Bandwidth:	15 kHz
Span:	1 MHz
Trace Mode:	Max Hold

Results:

As shown in the spectrum plot below, the measured 20 dB bandwidth of the given modulated signal is 232.372 kHz. This signal represents a data rate toward the upper limit of the capability of the narrowband AXM0F343, thus in most applications, 50 frequency hopping channels should be used .

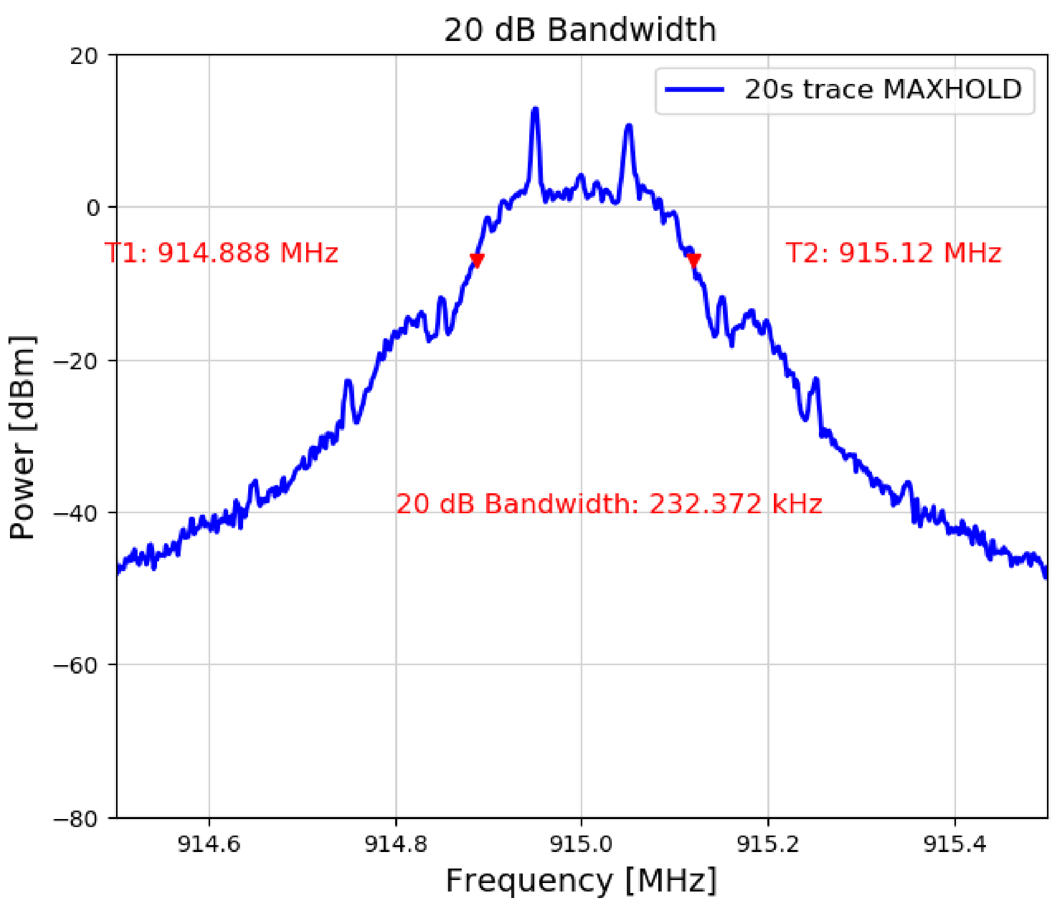


Figure 10.

Peak Conducted Power

Description:

This section demonstrates the procedure for measuring the peak output power. The limit defined in § 15.247(a)(2)(b)(2) is 1 watt, or 30 dBm.

Results:

The measured maximum output power of an AXM0F343−x−915−x−GEVB (shown below) is 14.45 dBm (cable loss not included), well below the limit. An external PA can be utilized to increase the output power.

Table 4.

Measurement Parameters	
Detector:	Positive Peak
Sweep Time:	Auto
Resolution Bandwidth:	200 kHz
Video Bandwidth:	200 kHz
Span:	1 MHz
Trace Mode:	Max Hold

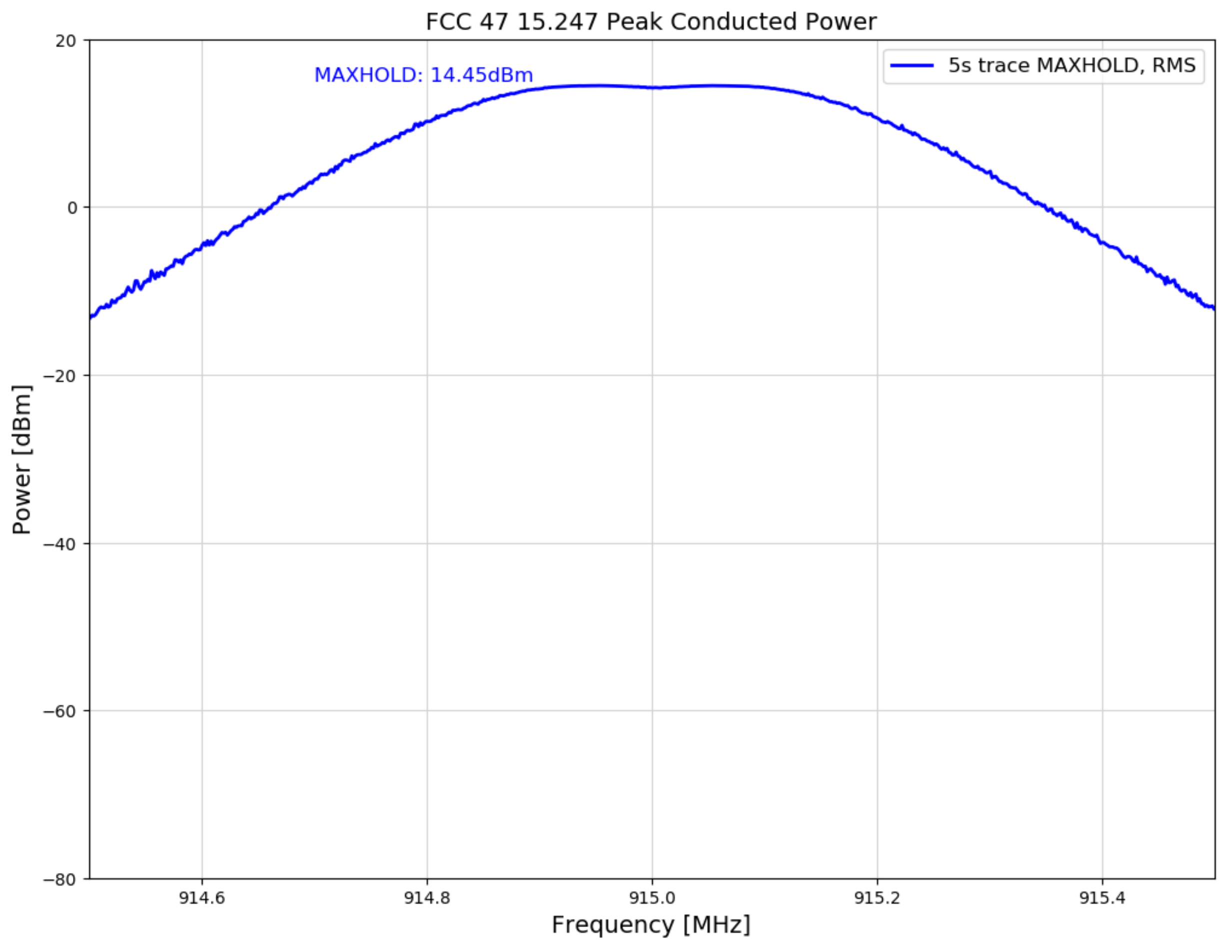


Figure 11.

Spurious Conducted Emissions

Description:

This test measures the output spectrum and verifies that the spurious emissions of the given modulated signal do not exceed the defined limits.

Table 5.

Measurement Parameters	
Detector:	Positive Peak
Sweep Time:	Auto
Resolution Bandwidth:	100 kHz
Video Bandwidth:	300 kHz
Span:	See Plots below
Test Signal:	Max Hold

Results:

The output spectrum plot is shown below, and is masked with the restricted bands and corresponding power limits. The power limits were calculated from the field strength limits given by § 15.205(a) and § 15.209(a) in the following manner:

$$P_{dBm} = 10\log_{10}\frac{P}{0.001} \quad \text{(eq. 1)}$$

Where

$$P = 0.3(E \cdot 1 \cdot 10^{-6})^2 \quad \text{(eq. 2)}$$

P is the conducted limit in Watts, P_{dBm} is the conducted limit in dBm, and E is the given field strength limit in μV/m.

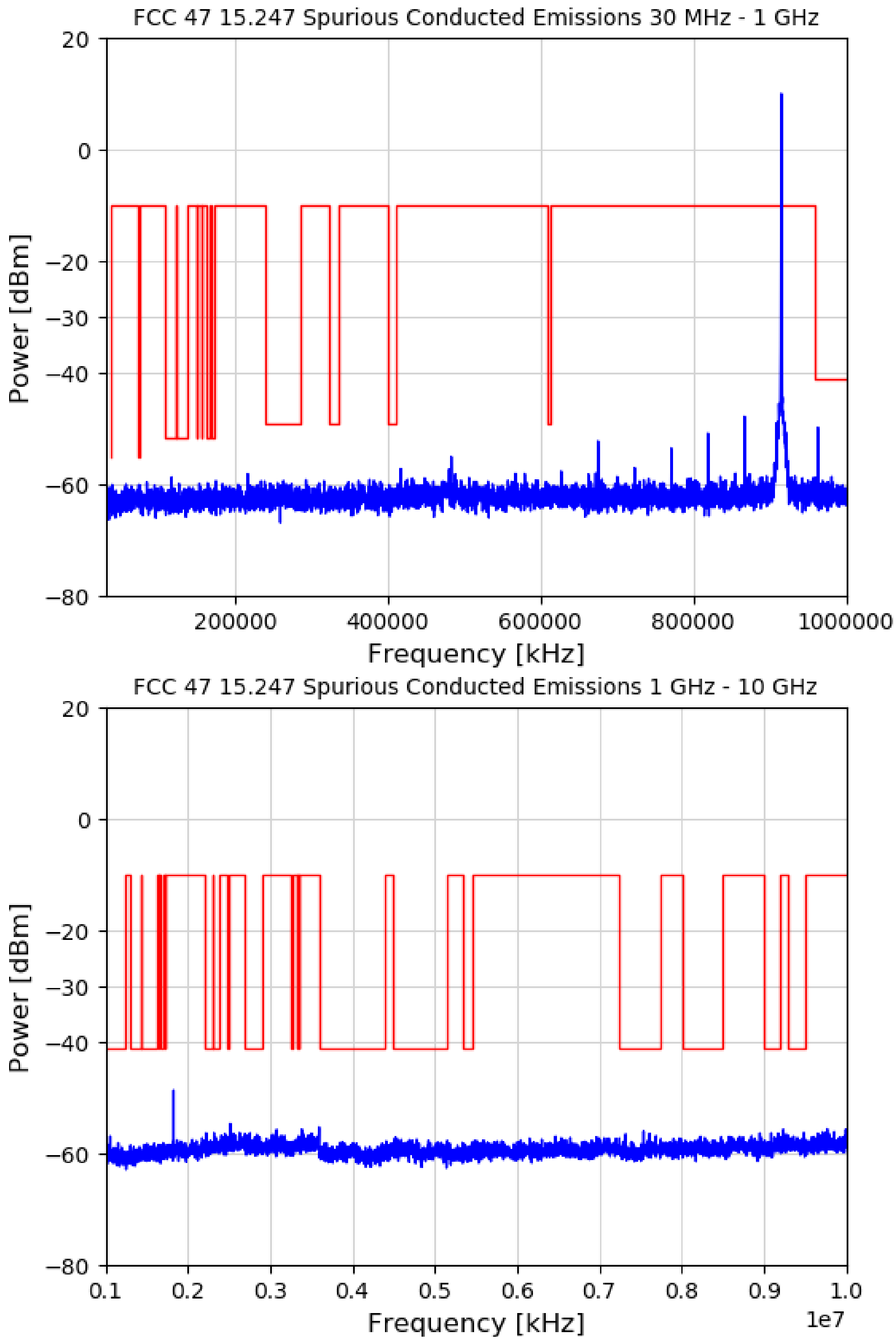

FCC 47 15.247 Spurious Conducted Emissions 30 MHz - 1 GHz
Power [dBm]
20
0
−20
−30
−40
−60
−80
200000
400000
600000
800000
1000000
Frequency [kHz]
FCC 47 15.247 Spurious Conducted Emissions 1 GHz - 10 GHz
Power [dBm]
20
0
−20
−30
−40
−60
−80
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1e7
Frequency [kHz]

Figure 12.

ADDITIONAL PERFORMANCE TESTS

TX Power vs. Current Consumption

The transmitter (TX) power and current consumption were measured with the test setup described previously and shown in Figure 7. The board was configured to transmit a Continuous Wave (CW) signal at 868.3 MHz. The transmit power level was measured using a spectrum analyzer (set to max−hold, with span = 500 kHz, RBW = 10 kHz, VBW = 30 kHz). Current was measured with a multimeter by probing the current monitor jumpers J7 (after removing R8). Current values represent the consumption by the radio core within the AXM0F343 SoC. Note that the matching network on the evaluation board has been optimized for maximum TX power output at 915 MHz. The component values can be modified to optimize power efficiency at lower TX output power levels. The measured TX powers (without cable loss) and current consumptions are shown in the table below:

Table 6.

915 MHz CW Output Power			
RadioLab PWR (dBm)	**PWRCOEFFB**	**Measured TX Power (dBm)**	**Radio Current J7 (mA)**
15	0x0FFF	14.53	58.96
10	0x0700	11.76	39.52
0	0x0207	3.42	18.76
−10	0x00AA	−6.42	11.92

RX Sensitivity

The receiver (RX) sensitivity was measured with the test setup described previously and shown in Figure 8. The board was configured to receive a FSK 1010 signal from the generator and send the calculated Bit Error Rate (BER) to the host PC via UART. The power of the modulated signal from Generator A was reduced until a BER of >0.001 (0.1%) was observed. The sensitivity values for different data rates (with modulation factor h = 0.66) are reported in the table below. The RX current value is also shown below, which was measured on J7.

Table 7.

915 MHz FSK Sensitivity				
Datarate (kbps)	**RX BW (kHz)**	**Measured Sensitivity (dBm) (w/o Cable Loss)**	**Reported RSSI (dBm)**	**Radio (J7) Current (mA)**
1	1	−124.5	−123	11.40
10	15	−117.5	−116	11.53
100	150	−107	−105	12.12
125	187.5	−105	−103	12.21

REFERENCES & LINKS

Product Page

1. AXM0F343 Device Page:
   https://www.onsemi.com/products/connectivity/wireless−rf−transceivers/axm0f343

FCC

1. US FCC 47 § 15.247:
   https://www.govinfo.gov/content/pkg/CFR−2013−title47−vol1/pdf/CFR−2013−title47−vol1−sec15−247.pdf
2. US FCC 47 § 15.249:
   https://www.govinfo.gov/content/pkg/CFR−2009−title47−vol1/pdf/CFR−2009−title47−vol1−sec15−249.pdf
3. US FCC 47 § 15.205:
   https://www.govinfo.gov/content/pkg/CFR−2001−title47−vol1/pdf/CFR−2001−title47−vol1−sec15−205.pdf
4. US FCC 47 § 15.209:
   https://www.govinfo.gov/content/pkg/CFR−2002−title47−vol1/pdf/CFR−2002−title47−vol1−sec15−209.pdf
5. Test procedures for measuring Digital Transmission System (DTS):
   https://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?switch=P&id=21124
6. ANSI C63.10:
   https://ieeexplore.ieee.org/document/6603246

Class−E Amplifier and Output Network Design

1. Post on the **onsemi** Community Forum
   https://www.onsemi.com/forum/t/faq−how−to−operate−ax5043−at−27−mhz/274
2. Load Network Design Techniques for Class E RF and Microwave Amplifiers:
   http://rfcafe−com.secure38.ezhostingserver.com/references/articles/Load−Network−Design−Techniques−for−Class−E−RF−and−Microwave−Amplifier.pdf
3. Analytical Design Equations for Class−E Power Amplifiers with Finite DC−Feed Inductance and Switch On−Resistance
   https://ris.utwente.nl/ws/files/5464094/analytical_design.pdf
4. Balun component calculator:
   http://analog.intgckts.com/impedance−matching/ lumped−lc−balun/

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